X-RAY TUBE COOLING COLLAR

DESCRIPTION

The present application relates to the x-ray tube arts. The invention finds particular application in conjunction with the cooling of a cathode assembly and will be described with particular reference thereto. It will be appreciated, however, that the invention also finds application in the transfer of heat to or from other cylindrical components.

Typically, an x-ray tube includes an evacuated envelope or frame made of metal, ceramic, or glass, which is supported within an x-ray tube housing. The x-ray tube housing and the frame define a cooling oil passage therebetween. Electrical connections are provided through the housing to the envelope. The envelope and the x-ray tube housing each include an x-ray transmissive window aligned with one another such that x-rays produced within the envelope may be directed to a patient or other subject under examination.

In order to produce x-rays, the envelope houses a cathode assembly and an anode assembly. The cathode assembly includes a cathode filament through which a heating current is passed. This current heats the filament sufficiently that a cloud of electrons is emitted, i.e. thermionic emission occurs. A high potential, on the order of 100-200 kV, is applied between the cathode assembly and the anode assembly.

This potential accelerates the electrons from the cathode assembly to the anode assembly through the evacuated region in the interior of the evacuated envelope. The electrons are focused onto a small area or focal spot on a target of anode assembly. The electron beam strikes the target with sufficient energy that x-rays are generated, along with large amounts of heat. A portion of the x-rays generated pass through the x-ray transmissive windows of the envelope and x-ray tube housing, toward the patient or subject under examination.

A deflecting cathode structure is sometimes used to move or wobble the electron beam, hence the focal spot, in a direction intersecting the circumferential direction of the anode rotation. An electromagnetic deflecting coil surrounds a neck of the housing where the cathode filament joins the envelope or insert frame. When an electric current is passed through the coil, an electromagnetic field is generated, deflecting the electron beam. Periodic shifting of the focal spot is used to reduce target loading and improve CT imaging resolution. However, a portion of the electrons are back scattered and strike the cathode housing. The area of the cathode neck joint, where the cathode housing is connected to the main body of the insert frame, is particularly prone to localized heating. Overheating of the cathode neck joint can cause joint failure and damage the hermetic seal of the x-ray tube.

In order to distribute the thermal loading created during the production of x-rays, a cooling fluid, such as oil, is circulated through the x-ray tube housing over the frame and cathode housing to aid in cooling components of the x-ray tube. Very high localized heating by the backscattered electrons also tends to deteriorate the quality of the cooling liquid, which eventually can lead to tube failure.

To reduce the localized heating adjacent the cathode housing neck, it is desirable for additional cooling liquid to be applied directly to the cathode neck area. Due to the high flow resistance of components surrounding the cathode neck, however, such as the filament deflection coil, the cooling fluid has difficulty in reaching the neck region.

One method to overcome this has been to place a collar around the cathode neck joint with an inlet and an outlet. Cooling fluid is forced through the inlet and is divided into two subflows, each of the subflows passing 180° around one side of the neck joint. The subflows merge and exit at the outlet at the opposite side. As a result, the area closest to the inlet receives the most efficient cooling as the fluid is steadily heated toward the outlet. Moreover,

a flow stagnation zone occurs adjacent the neck where the two subflows merge, leading to poor localized cooling of the joint in that region. Additionally, the bottom part of the cathode housing is poorly cooled because of the lack of flow in that region. As a result, uneven cooling of the cathode neck joint tends to occur.

The present invention provides a new and improved method and apparatus which overcome the above-referenced problems and others.

In accordance with one aspect of the present invention, a cooling device for an associated x-ray tube is provided. The cooling device includes a fluid inlet which receives a supply of cooling fluid from an associated source. A hollow cover member is in fluid communication with the inlet. The cover member includes a wall which defines an aperture sized for receiving a portion of the associated x-ray tube therethrough. The cover member defines an interior annular flow path for cooling fluid to circulate around the portion of the associated x-ray tube. The aperture of the cover member is configured for providing at least one fluid outlet through which cooling fluid exits the cover member at a plurality of locations around the portion of the associated x-ray tube.

In accordance with another aspect of the present invention, an x-ray tube assembly is provided which includes the cooling device described above.

In accordance with another aspect of the present invention, a method of cooling a neck of an x-ray tube is provided. The method includes mounting the cooling device described above around the neck.

One advantage of at least one embodiment of the present invention is that overheating of a cathode neck joint is alleviated.

Another advantage of at least one embodiment of the present invention is that it extends x-ray tube life.

Another advantage resides in reducing premature tube failure.

Still further advantages of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the following detailed description of the preferred embodiments.

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating a preferred embodiment and are not to be construed as limiting the invention.

FIGURE 1 is a diagrammatic illustration, partially cut away, of an x-ray tube assembly and a cooling system according to one embodiment of the present invention;

FIGURE 2 is a perspective view of the x-ray tube and cooling collar of FIGURE 1;

FIGURE 3 is an enlarged top plan view of a first embodiment of the cooling collar of FIGURE 2;

FIGURE 4 is a bottom plan view of the cooling collar of FIGURE 3;

FIGURE 5 is a top perspective view of the cooling collar of FIGURE 3;

FIGURE 6 is a bottom perspective view of the cooling collar of FIGURE 3;

FIGURE 7 is a top diagrammatic view of the x-ray tube frame top piece and the cooling collar of FIGURE 3, showing the direction of fluid flow;

FIGURE 8 is an enlarged side sectional view through Y-Y of FIGURE 3 of the cooling collar mounted on the top of the x-ray tube surrounding the cathode housing neck;

FIGURE 9 is a top plan view of a cooling collar for the x-ray tube of FIGURE 1 according to a second embodiment of the present invention; and

FIGURE 10 is a top perspective view of a cooling collar for an x-ray tube according to a third embodiment of the present invention.

With reference to **FIGURE 1**, a rotating anode x-ray tube assembly **1** of the type used in medical diagnostic systems, such as computed tomography (CT) scanners, provides a beam of x-ray radiation. The assembly **1** includes an anode **10** which is rotatably mounted in an evacuated chamber **12**, defined by an envelope or insert frame **14**, typically formed from glass, ceramic, and/or metal. A cathode assembly **18** supplies and focuses an electron beam **A**. The cathode assembly includes a source of electrons **20**, such as a thermionic filament. The filament **20** is biased, relative to the anode **10**, such that electrons are accelerated toward the anode and strike a target area **22** of the anode. A portion of the electrons striking the target area **22** is converted to x-rays, which are emitted from the x-ray tube through a window **24** in the envelope (in the cut away section toward the viewer in **FIGURE 1**). The X-radiation is used for diagnostic imaging, therapy treatment, and the like. The insert frame **14**, cathode assembly **18**, **and** anode **10** together comprise an x-ray tube **26** of the assembly **1**.

With reference also to **FIGURE 2**, the cathode assembly **18** includes a cathode housing or cup **30**, which houses the filament **20**. The housing **30** is mounted to a cathode plate **32** which forms an end wall of the insert frame **14**. The cathode housing **30** narrows, adjacent to the cathode plate, to define an annular region of reduced width or neck **34**. A distal end **36** of the neck **34** is welded or otherwise mounted and sealed to the cathode plate **32** at a neck joint **38**, around an opening **39** in the plate, such that the neck extends generally perpendicular to the plate.

The cathode housing **30** serves to focus the electrons emitted from the cathode filament **20** to a focal spot on the anode target area **22**. In one embodiment, the

cathode housing **20** is at an electrical potential of about -75,000 volts with respect to ground, and the anode **10** is at an electrical potential of about +75,000 volts with respect to ground, the potential difference between the two components thus being about 150,000 volts.

With continued reference to **FIGURE 1**, a C-shaped electromagnetic deflecting coil **40** partially surrounds the cathode housing **30** in the region of the neck **34**. By selectively applying a current to the coil **40**, an electromagnetic field is created which deflects the beam of electrons, allowing the focal spot to be shifted, periodically, on the anode target area **22**, thereby reducing the focal spot temperature.

An x-ray tube housing **50**, filled with a heat transfer and electrically insulating fluid, such as oil, surrounds the envelope **14**. A cooling system **52** receives heated cooling liquid from the housing through an outlet line **54** and returns cooled cooling liquid via a return line **56**. The lines **54, 56** may be in the form of flexible hoses, metal tubes, or the like. The cooling system **52** includes a pump **57** and a heat exchanger (not shown). When returned to the housing **50**, the cooled cooling liquid flows past the window **24**, and around a bearing assembly **58** for the anode, the cathode assembly **18**, and other heat-dissipating components of the x-ray tube **26**.

A portion of the electrons striking the anode **10** is not converted to x-rays, but rather is backscattered, towards the cathode housing **30**. The backscattered electrons strike the cathode housing **30**, primarily in the area of the neck **34**, which becomes heated thereby. Heat also flows from the neck **34** into a lower end **60** of the cathode housing **30**, which also tends to become heated.

A cooling device **70** in the form of a cooling collar surrounds the neck **34** of the cathode housing **30**. In one embodiment, as shown in **FIGURE 1**, the cooling collar **70** is located intermediate the plate **32** and the deflecting coil **40**. The cooling collar **70** includes an inlet tube **72**, through

which a cooling fluid, such as the cooling liquid used to cool the housing **50** is fed to the collar. The cooling liquid inlet tube **72** is fluidly connected with the cooling system **52** (or with a separate cooling system) which supplies cooled cooling liquid to the inlet tube **72** via a cooling collar fluid line **74**. The pump **57** ensures that the collar **70** receives a continuous flow of cooling liquid when the x-ray tube **26** is operating. Optionally, a T-connector **78** splits the flow of cooling liquid into two flow paths, along lines **56** and **74** respectively, such that some of the cooling liquid flows directly to the housing **50**, without passing through the collar. Alternatively, the line **54** is omitted and all of the cooling liquid is directed first to the cooling collar **70** and from there enter the main cooling housing **50** of the x-ray tube, or vice versa.

The cooling collar **70** may be formed from metal, ceramic, heat resistant plastic, or the like and may be removably attached, welded, or otherwise fixed to the base plate **32**.

With reference now to **FIGURE 3**, the cooling collar **70** includes first and second side portions **80, 82**, which are joined or butted together, during assembly, around the neck at a seam **84**. The assembled cooling collar **70** includes a generally planar base plate **86** configured for attachment to the cathode plate **32**. Specifically, the base plate **86** includes a generally annular central region **88** from which first and second mounting brackets **90, 92** extend in opposite directions. The central region **88** is positioned to contact the base plate **32** with its lower surface. The mounting brackets **90, 92** define semicircular cutouts **94, 96**, respectively at distal ends thereof. The mounting brackets **90, 92** are mounted to suitably positioned threaded studs **98**, which are welded to the cathode plate **32** and held in place by threaded nuts **100** (**FIG. 2**).

The seam **84** need not be welded or otherwise form a fluid tight joint between the two portions **80, 82**, since a small amount of leakage through the seam does not impact the

effectiveness of the cooling collar **70**. In general, the coil **40**, in cooperation with the studs **98** and nuts **100**, is sufficient to keep the two portions **80**, **82** in sufficient contact at the seam **84** to reduce leakage through the seam to a minimum.

As shown in **FIGURES 4** and **5**, a hollow cover member **110** is connected with the base plate **86** and extends away from the plate to define an annular interior space **111** for cooling liquid to circulate. The cover member **110** defines, at least in part, an interior fluid flow path **112** (indicated by arrows in **FIGURE 4**), along which the cooling liquid flows. The adjacent exposed portions of the neck **34** and plate **32** also partly define the flow path **112**. The cover member **110** includes an elongate inlet portion **114**, aligned with one of the mounting brackets **90**, which is connected with the inlet tube **72** at a distal end thereof. The inlet portion **114**, in cooperation with the exposed portion of the plate **32** beneath, defines a first portion **115** of the fluid flow path **112**.

As best shown in **FIGURE 5**, the inlet portion **114** has a raised vertical sidewall **116** covered by a top member or wall **118** at an upper end thereof. The terms "upper" and "lower" and the like are used with respect to the orientation of the x-ray tube **26** as illustrated in **FIGURE 1**. It will be appreciated that in use, the x-ray tube may have a different orientation.

The inlet portion **114** is connected with an annular central portion **120** of the cover member **110**. The central portion **120** is stepped to create a support surface for the deflecting magnet **40**. In particular, upper and lower generally annular concentric raised portions or steps **122**, **124** are defined, the lower step **124** being of larger interior diameter to support the magnet and the upper step **122** having another diameter to match the magnet inner diameter. The upper step **122** has a central aperture **126** which is preferably concentric with the two steps and sized to match the neck **34**. The upper annular step **122** has a vertical sidewall **128** which extends around the aperture **126** from the sidewall **116** of the

inlet portion **114**, but is of reduced height, as compared with sidewall **116**, due to the lower step **124**. The top member **118** of the inlet portion **114** extends across the sidewall **128** of the upper step **122** and includes an annular portion **130** which defines the central aperture **126** therein.

The lower step **124** includes a vertical sidewall **132** and a generally annular shelf **134 (FIGURE 8)** which extends between the sidewall **132** and the sidewall **128** of the upper step **122**. In the illustrated embodiment, the top member **118**, shelf **134**, and base plate **86** are all parallel with one another and with the plate **32**, and are perpendicular to the sidewalls **116**, **128**, **132**, although it is also contemplated that inwardly or outwardly curved or sloped sidewalls **116**, **128**, **132** may be employed and/or that the shelf **134** and top member **118** may be curved or sloped, rather than flat. Additionally, while two steps **122**, **124** are shown, it is contemplated that these may be combined into a single step, or that more than two steps may be provided.

With reference once more to **FIGURE 3**, the aperture **126** has an interior diameter **D** which is close to or slightly larger than that of the neck **34** to accommodate the neck snugly therein. Angularly spaced notches **140** are formed around a perimeter **142** of the aperture **126** and serve as flow outlets for the cooling liquid. The notches **140** are shown as semicircular cut outs which extend radially outward from the aperture **126**, although notches of other shapes are contemplated. As shown in **FIGURE 4**, the cooling liquid flows around the neck **34** in the upper step **122** and exits the cooling collar through the notches **140**.

The notches **140** have a much smaller diameter than the aperture **126**. For example, the notches may have a diameter or width of about 0.05-0.2 cm, e.g., about 0.1 cm, and the aperture a diameter **D** of about 2-3 cm, depending on the size of the cathode neck **34**. The cathode neck may have a diameter which is 0.01-0.3 cm less than the diameter **D**. Thus, a ratio of the diameter of the notches **140** to the diameter of the aperture **126** may be from about 1:60 to about

1:10. There may be from about 8 to about 30 notches **140** spaced around the perimeter **142** of the aperture **126**, preferably, about 15 to 20. Preferably, at least some of the notches **140** are located in each of four separate quadrants of the aperture **126**, irrespective of the selected angular positions of the four quadrants.

The majority of, and preferably substantially all of the cooling fluid which enters the fluid flow path **112** exits the cooling device **70** through the aperture **126** and its associated notches **140**. The cooling liquid exits the notches **140** as jets, aiding the mixing of cooling liquid in the region of the neck **34** and thus improving heat transfer away from the neck. Although small amounts of cooling liquid may leak from around the base plate **32** or through the seam **84**, this preferably accounts for less than about 20% of the total fluid flowing in the flow path **112**, generally less than about 10%.

As shown in **FIGURES 4**, **6**, and **7**, baffle **144** in the form of a generally vertical wall is mounted across the interior of the inlet portion **114**. The baffle **144**, which in the illustrated embodiment is tangential with the circumference of the neck **34**, ensures a generally unidirectional circular flow of cooling fluid around the neck **34**, as shown by the arrows in **FIGURE 4**. It will be appreciated that it is the component of the flow that is in the horizontal plane (parallel with the plate) which follows this circular path, and that a vertical component of the flow causes the liquid to move in an upward direction, toward the notches **140**. The illustrated horizontal flow component is anticlockwise, although it will be appreciated that in an alternative embodiment, with the baffle oriented at 180° to its illustrated orientation, a clockwise flow is created. A tangential orientation of the baffle **144** reduces flow resistance, although other orientations are also contemplated.

The baffle **144** extends in both the upper and lower steps **122**, **124**, contacting or closely adjacent to the plate

32 at its lower end and perpendicular to the plate. The baffle is attached to the top member **118** at its upper end, joined to the sidewall **116** at its inlet end, and is closely spaced from, or touches the neck **34** at its outlet end. This ensures that substantially all cooling liquid flows in the same generally circular direction. A small amount of cooling liquid may leak out between the baffle **144** and the plate **32** or neck **34** but this does not significantly affect the cooling properties and the circular flow.

As shown in **FIGURE 4**, the baffle **144** defines first and second opposed vertical side surfaces **146**, **148**. The first vertical surface **146** defines, in part, an inlet end **150** of an annular portion **152** of the fluid flow path **112** and the second surface **148** defines a terminal end **154** of the annular portion **152** of the fluid flow path. Thus, cooling liquid flows around the neck **34** and the adjacent neck joint **38** in substantially a full circle (i.e., at least about 80% of a full circle, more preferably, at least 95% of a full circle), contacting side surfaces **146**, **148** of the baffle **144** at the beginning and at the end of the annular portion **152** of the fluid flow path.

Not all of the cooling fluid completes the annular portion **152** of the fluid flow path, however. As the cooling liquid flows around the cathode housing neck **34**, a portion of the cooling liquid begins to exit at the top **118** of the collar **70**, between the collar and the neck. A significant portion of the cooling liquid exits through the notches **140**, although some fluid may also leak through an annular gap **156**, where present, between the neck **34** and the collar aperture **126**. As shown by the flow arrows in **FIGURE 4**, the cooling liquid exits the collar at a plurality of angularly spaced locations around the full circumference of the neck **34**. Where the collar fits the neck snugly, the locations are essentially discrete regions, defined by the notches **140**. Where there is a gap **156** between the collar **70** and the neck, the locations are essentially continuous, but with somewhat higher fluid flows at the notches **140**. The escaping liquid

from the collar impinges on the lower portion **60** of the cathode housing **30**, as shown in **FIGURE 1**, thus cooling both the neck and the portions of the cathode housing which have a tendency to become overheated.

The annular, generally unidirectional flow of the cooling fluid in the flow path portion **152** ensures that there is no stagnation zone in the flow which typically occurs when two fluid flow paths are used, one on each side of the neck. As a result, localized overheating of the neck **34** is reduced.

As the cooling liquid flows out of the notches **140**, there is a pressure drop in the remaining cooling liquid in the collar, i.e., the cooling liquid pressure tends to decrease from the inlet end **150** to the terminal end **154** of the flow path portion **152**, which defines the end of the flow path **112**. To maintain a relatively uniform outlet flow between the collar **70** and the neck **34** around the full circumference of the neck, an angular spacing **s** between notches gradually decreases or the notch size increases toward the terminal end **154** of the flow path **112**. The spacing **s** is selected to compensate for pressure losses along the direction of flow. Thus, for example, as seen in **FIGURE 3**, the notches **140** are spaced about 30° apart near the inlet end **150**, but toward the terminal end **154**, the notches become steadily closer together until they are essentially contiguous.

Rather than discharging all of the cooling liquid at one side of the cathode neck **34**, the cooling fluid is gradually released from the top **118** of the cooling collar **70** around the entire perimeter of the neck **34**. This eliminates the flow stagnation zone which tends to occur when the fluid is all (or primarily all) released from a single side outlet in line with the inlet.

While in the illustrated embodiment, a generally uniform outlet flow is achieved by increasing the frequency of the notches, alternatively, or additionally, the notches may increase in size toward the terminal end **154**.

By performing theoretical calculations (e.g., a computer simulation) on expected neck or collar temperatures, cooling fluid flow velocities, or cooling fluid pressures under anticipated flow conditions, or by conducting actual measurements during operation of the x-ray tube **26**, the optimum spacing **s** and/or size of the notches **140** can be selected so as to maintain an even flow velocity and/or reduce variations in the neck temperature around the circumference.

As shown in **FIGURE 4**, the cooling liquid flows both around the upper step **122** and also around the lower step **124**. As illustrated in **FIGURE 8**, the collar defines a lower open end **160** having the same internal diameter as the lower step **124**. The cooling fluid flowing in the lower step **124** thus contacts both a lower portion of the neck **34** and the plate **32** in the region of the neck joint **38**. As cooling liquid exits from the upper step **122**, some of the cooling fluid in the lower step **124** moves upwardly into the upper step, thus carrying away heat from the neck joint **38**. The steps **122**, **124** are sized to permit the deflector coil **40** to be seated on the shelf **134** of the lower step **124**.

Although described in terms of two steps, it is also contemplated that the shelf **134** may be contiguous with the top member **118**, for example, where the distance between the collar and the lower portion **60** of the cathode housing is sufficient to permit the coil **40** to be seated therebetween. Alternatively, the coil may be located elsewhere in the x-ray tube housing, or alternatively, eliminated if focal spot adjustment is not required.

In another embodiment (not shown), the base plate **86** extends beneath one or both of the steps **122**, **124**, reducing the size of the opening **160** to one closer to the diameter of the neck.

With reference now to **FIGURE 9**, another embodiment of a cooling collar **70'** is shown, where similar elements are numbered with a primed suffix (') and new elements are accorded new numerals. The cooling collar **70'** is similar to

cooling collar **70**, except as otherwise noted. As with cooling collar **70**, cooling liquid enters the cooling collar **70'** via an inlet tube **72'** and is directed by a baffle **144'** in an annular flow path **152'** around the neck **34** of the cathode housing. However, in this embodiment, the aperture **126'** is not equally spaced from the neck **34** around its perimeter **142'**, but has a gap **156'** which increases in width from the inlet end **150'** to the outlet end **154'** of the flow path **152'**. The aperture **126'** thus has a spiral shape, rather than being circular. The width of the gap **156'** is selected to at least partially compensate for the pressure drop in the cooling fluid along the flow path portion. In this way, variations in temperature around the neck are minimized and/or outlet flow velocities around the neck are relatively uniform.

In the embodiment of **FIGURE 9**, there are no discrete notches and the cooling fluid thus exits generally uniformly around the circumference of the neck **34**. However, in an alternative embodiment (not shown), notches similar to notches **140** are provided around the aperture **126'**.

With reference now to **FIGURE 10**, another embodiment of a cooling collar **70''** is shown, where similar elements are numbered with a primed suffix ('') and new elements are accorded new numerals. The cooling collar **70''** is similar to cooling collar **70**, except as otherwise noted. In this embodiment, the collar **70''** provides a means for supplying a cooling liquid flow to the housing **50**. Specifically, an outlet tube **170** extends from the cooling collar elongate inlet portion **114''**, through which a portion of the cooling liquid exits the collar **70''**. Thus, the cooling liquid entering through the inlet tube **72''** is split into two subflows, a first subflow **174** which passes along the inlet portion **114''** to the annular portion **152''** of the flow path **112**, and a second subflow **176** which passes out of the cooling collar through outlet **170**, prior to reaching the annular portion **152''** of the flow path **112''**. The second subflow **176** of the cooling liquid passes directly to the housing **50** and flows past other portions of the x-ray tube **26**, such as the

window **24** and anode bearings **58** to cool these components. The first subflow **174** of the fluid flow combines with the second subflow **176** when it exits through the top **118''** of the collar **70''**.

The outlet tube **170** has an internal diameter which is selected so as to maintain an adequate supply of cooling liquid to the collar **70''**, as well as to the housing **50**. For example, the internal diameter of the inlet tube **72''** is greater than the internal diameter of the outlet tube **170**. In one embodiment, a ratio of the internal diameter of the inlet tube to the internal diameter of the outlet tube is from about 2:1 to about 2:1.5. For example, the diameter of the inlet tube may be about 1.0 cm and the diameter of the outlet tube may be about 0.64 cm. In one embodiment, a ratio of the fluid flow rate of subflow **174** directed through the inlet portion **114''**to a fluid flow rate of subflow **176** exiting through the outlet tube **170** is in the range of from about 1:3 to about 1:1.5. For example, the fluid flow in subflow **174** may be about 1.4 grams/minute, while the fluid flow in subflow **176** may be about 2.6 grams/minute.

This embodiment has the advantage that fresh cooling fluid flows over the window **24** of the x-ray tube **26**, providing a higher level of cooling than if it is cooled with cooling fluid which has all passed through the collar and around the neck of the cathode housing.

It will be appreciated that in another alternative embodiment a cooling collar similar to collar **70'** may be formed with an outlet similar to outlet **170**.

In yet another embodiment (not shown), the tendency for a reduction in pressure to occur as cooling liquid exits the cover member is at least partly counterbalanced by a steady decrease in width of the annular portion of the cover member from the inlet end **150** to the terminal end **154** of the flow path **112**. This helps to minimize the pressure drop as cooling liquid exits the collar. In this embodiment, the notches may be eliminated. The aperture in the top member

may be circular, as for aperture **126**, or spiral, as for aperture **126'**.

Without intending to limit the scope of the invention, the following example demonstrates the effectiveness of the cooling collar at maintaining even cooling of a neck of a cathode housing.

EXAMPLE

A computer simulation was conducted to generate a velocity distribution profile of a cooling collar of the design shown in **FIGURE 10** during operation of an x-ray tube of the type shown in **FIGURE 1**. The inlet tube has an ID of 1.0 cm and the outlet tube an ID of 0.63 cm. The inlet flow rate is 3.12 m/s (4.0 grams/minute) and the outlet tube flow rate is 2.61 grams/minute. There are seventeen notches around the aperture. Each of the notches has a radius of 0.1 cm. The inlet fluid temperature is set at 40°C, which is approximately the same as the temperature of the outlet subflow.

Improved flow distribution and reduced stagnation are found with the present cooling system as compared with a cooling collar with a single outlet, diametrically opposite the inlet.

The invention has been described with reference to the preferred embodiment. Modifications and alterations will occur to others upon a reading and understanding of the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.